Cryogenics at The European Spallation Source

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July 2014
Outline

• Introduction to ESS
• Applications of Cryogenics at ESS
  • Accelerator Cryoplant
  • Cryogenic Distribution System
  • Target Moderator Cryoplant
  • Test and Instruments Cryoplant
• He Recovery and Storage
• Energy Recovery
• Opportunities for In-Kind Contributions
• Summary
The goal of ESS is to provide a spallation based neutron source significantly more powerful than existing sources: 30 times brighter than ILL and 5 times more powerful than SNS.

This facility will enable neutron based research in a wide range of fields including: materials science, condensed matter and biomedical studies.
Why Neutrons?
Neutrons and x-rays are complementary
- neutrons...

..see magnetic atoms

..see inside materials

..see light atoms

..see atoms move

..see isotopes

Courtesy of Ian S. Anderson
ESS - Bridging the neutron gap

ESS Overview

5 Times more powerful than SNS
30 times brighter than ILL

Linear proton accelerator (600 m)

Target station

Neutron science systems
A European Science Project

Swedish, Denmark and Norway:
50% of construction and
20% of operations costs

European partners pay the rest
The view of the Southwest in 2025

- MAX IV – a national research facility, under construction, opens up in 2016
- Science City – a new part of town
- ESS – an international research facility

Lund (113,500)
Malmö (309,000)
Copenhagen (1,200,000)
## ESS Linac

### Table: Linac Parameters

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (MeV)</th>
<th>No. of Modules</th>
<th>No. of Cavities</th>
<th>$\beta$ g</th>
<th>Temp (K)</th>
<th>Cryo Length (m)</th>
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<td><strong>Spoke</strong></td>
<td>220</td>
<td>13</td>
<td>$2 (2S) \times 13$</td>
<td>0.5 $\beta_{opt}$</td>
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<td><strong>Medium $\beta$</strong></td>
<td>570</td>
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<td>$4 (6C) \times 9$</td>
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Prototyping the ESS accelerator

Sebastien Bousson

Pierre Bosland

CERN

Roger Barlow

Ibon Bustinduy

Søren Pape Møller

Roger Ruber

Anders J Johansson

The National Center for Nuclear Research, Swierk

Santo Gammino
Applications of Cryogenics at ESS

- Cooling for the cryomodules (2 K, 4.5 – 300 K and 40 K)
- Cooling for the Target supercritical H₂ Moderator (16.5 K)
- Liquid Helium and Liquid Nitrogen for the Neutron Instruments
- Cooling for the cryomodule test stand (2 K, 4.5 – 300 K and 40 K)
- This is accomplished via 3 separate cryoplants
Accelerator Cryogenics

• Bulk of acceleration is carried out via 3 classes of SRF cavities: Spoke, Medium ($\beta = 0.67$) Beta Elliptical and High ($\beta = 0.86$) Beta Elliptical

• No superconducting magnets in the accelerator. There are some in the instruments

• Cavities operate at 2 K with a 40 – 50 K thermal shield

• Inner power coupler cooling from 4.2 K to 300 K

• Accelerator lattice permits an 14 additional cryomodules to compensate for lower than expected cryomodule gradients (Stage 2)
Elliptical Cryomodule Components

- 5-cell elliptical cavity
- Cold tuning System
- Space frame
- Ti Helium tank
- Power coupler

Diameter 1200 mm

6600 mm

Figure 4.120: Helium vessel with hanging rod
July 2014

TTC@DESY – C. Darve – 24/03/14
Spoke cavity string and cryomodule package

Diameter: 1350 mm

July 2014

IceC 25 - J.G. Weisend II
## Cryomodule Heat Load Distribution

<table>
<thead>
<tr>
<th></th>
<th>Watts to 2 K</th>
<th>4.5 K Liquefaction (g/s)</th>
<th>Watts to ~50 K</th>
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<tr>
<td></td>
<td>Static</td>
<td>Dynamic</td>
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<td>Others</td>
<td>Valves</td>
<td>Coupler</td>
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<tr>
<td>1 Spoke</td>
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<tr>
<td>1 MB</td>
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<td>0.2</td>
<td>6.8</td>
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<tr>
<td>1 HB</td>
<td>6.3</td>
<td>0.2</td>
<td>6.8</td>
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</table>
Connection between Elliptical Cavity CM and Cryogenic Distribution Line

He II produced at each CM
ESS Accelerator Cryoplant (ACCP)

- Provides cryogenic cooling to Cryomodules
  - 13 Spoke and 30 Elliptical (Stage 1)
  - Sized to allow an additional 14 Elliptical Cryomodules for design contingency (Stage 2)
- Allows for number of operating modes
- Connected to the cryomodules via a cryogenic distribution system
- High availability and turn down capability are important features
- Compressor heat is absorbed by Lund District Heating System (unique ESS feature)
## ACCP Capacities

<table>
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<tr>
<th>Operation modes</th>
<th>2 K Load, W</th>
<th>4.5 K Load</th>
<th>40-50 K, W</th>
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<td>2478</td>
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<td>Turndown</td>
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<td>1472</td>
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<td>Standby</td>
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<td>TS Standby</td>
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<td>Maximal Liquefaction</td>
<td>Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank</td>
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<tr>
<td>Nominal</td>
<td>2226</td>
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ACCP Status

• Heat loads and capacities determined
• Industry studies completed
• Design choices have been made
  • No LN₂ precooling
  • Optimized cold compressor and turboexpander hardware for Stage 1 & Stage 2 to minimize energy consumption
• Detailed Specification and SOW complete and ITT released
• Expected placement of order in February 2015
  • Installation, LHe and GHe storage and Helium Recovery will be separate procurements
• Plant is expected to fully commissioned by June 2018
Cryogenic Distribution System

- Allows warm up and cool down of one or more cryomodules w/o affecting remaining cryomodules
- Connection between distribution line & cryomodule is done via fixed connections
- Separate isolation vacuums in the distribution lines and cryomodules
- Operating modes defined
- Conceptual design complete
- Detailed design and production via IKC or commercial contract will start by Q3 2014
- Cryogenic Distribution System must be complete and installed by December of 2017
Cryogenic System of the Optimus Linac

- **Linac Cryoplant**
- **Cryogenic Transfer Line (75 m)**
- **Splitting box**
- **Cryogenic Distribution Line (310 m)** comprising 43 valve boxes
- **Auxiliary process lines**
- **Endbox**

- **21 High Beta Cryomodules (174 m)**
- **9 Medium Beta Cryomodules (75 m)**
- **13 Spoke Cryomodules (54 m)**

Superconducting section of the Optimus Linac (303 m)
Valve box – vacuum jacket

- Jumper connection vacuum jacket with a lateral compensators (vertical: DN350 horizontal: DN450)
- Cryoline interconnection sleeve with axial compensator (DN600)
- Cryoline vacuum jacket (DN550)
- Interconnection sleeve at the interface to the cryomodule
- Valve box supports
- Bottom plate (demountable)
Cryogenic Distribution Line
Elliptical Cryomodules in ESS Tunnel
Target Moderator Cryoplant

- Cools the Supercritical H₂ neutron moderators that surround the target

- Provides 20 kW of cooling at 16.5 K via GHe to the He/supercritical H₂ heat exchanger
  - Moderator design is still under development and final heat load won’t be known until summer 2014
  - ESS Target Division responsible for the supercritical H₂ system

- Compressor heat is absorbed by Lund District Heating System (unique ESS feature)

- Cryoplant should be ordered in August of 2015 and fully commissioned by June of 2018
Draft Schematic of LH$_2$ Moderator Loop showing connection to the Target Cryoplant
Test and Instruments Cryoplant

- Provides cooling at 2 K, 40 K and 4.5 K liquefaction for elliptical cryomodule testing
  - 2 K operation done via warm vacuum pumps

- During ESS operations, provides up to 7500 l per month of LHe to the instruments
  - Helium is recovered, purified and reliquefied

- Sufficient LHe storage planned to allow several weeks of Science Ops in the case of cryoplant failure
Test and Instruments Cryoplant
Capacity and Status

• The plant will produce:
  • 75 W @ 2 K,
  • 422 W @ 40 K
  • 0.4 g/s at 4.5 K for coupler cooling

• A plant this size exceeds the 7500 l/month liquefaction requirement

• Cryoplant should be ordered in August 2015 and fully commissioned by July 2017
Cryomodule Test Stand Showing Connection to T&I Cryoplant

- 2 modulators
- 4 klystrons
- test stand bunker
- cryo and TS control room
- equipment access door
- cryogenic transfer line
- cryomodule loading area
Helium Recovery and Storage

- The ESS goal is to recovery, purify and reuse as much He as possible
- ACCP and TICP cryoplants will share a common gas system while TMCP has separate storage that can be cross connected
- The system will include a separate cryogenic purifier
- Systems will be provided by IKC or separate contracts
- Expected He Storage Capacities:
  - LHe
    - 20 m³ (Includes storage for second fill of linac)
    - 5 m³ (Backup for Instruments He)
  - GHe (20 Bar)
    - 900 m³ - sufficient to hold all the linac inventory
  - GHe (200 Bar)
    - 12 m³ - Instrument He storage
Conceptual ESS Cold Box Room Layout
The ESS Commitment: A Sustainable Research Centre

- Responsible
  Energy Efficiency
- Recyclable
  ESS’s cooling is Lund’s heating
- Renewable
  Power from renewable sources
Energy Inventory ESS 2012

250 GWh renewable power

- Ion Source: 3 MW
- Accelerator incl klystron gallery: 17 MW
- Cooling: 8 MW
- Target station: 2 MW
- Target cryo: 3 MW
- Accelerator cryogenics: 4 MW
- Instruments: 1 MW

Total max load: 38 MW (Goal 35)
Total annual: 250 GWh

174 GWh re-used heat = 70% (excluding heat pumps)

49 GWh @ 20°C
34 GWh @ 40°C
91 GWh @ 90°C
Opportunities for In Kind Contributions to the ESS Cryogenic System

• There are many opportunities for IKC in the ESS Cryogenics System and we are very happy to discuss any of them.

• Possibilities include:
  • Cryoplants (particularly the TMCP and TICP)
  • Cryogenic Distribution System
  • He Recovery and storage
  • Assistance with installation and commissioning
ESS Cryogenic System

Pure Helium Gas Storage 1

Standalone Helium Purifier

Helium Recovery System

Pure Helium Gas Storage 2

Accelerator Cryoplant

20 m³ LHe Tank

5 m³ LHe Tank

Test & Instrument Cryoplant

LHe Mobile Dewars

Target Moderator Cryoplant

Target Distribution System

Hydrogen Circulation Box

Hydrogen Moderator

Cryogenic Distribution System

LN2 Storage Tanks

LN2 Mobile Dewars

Instruments & Experiments

Cryomodule Test Stand

Cryomodules

IEEE/CSC SUPERCONDUCTIVITY NEWS FORUM (global edition) July 2014
Presentation given at ICEC25 – ICMC2014, Enschede, July 2014

July 2014  ICEC 25 - J.G. Weisend II
# High Level Schedule

## Master Schedule - WP11 Cryogenics

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**Milestones:**
- **CE: FULL ACCESS TO TEST FACILITY, COMPRESSOR BUILDING ADN COLDBOX HALL (on September the 9th, 2016)**
- **First Protons on Target 570 MeV (on May the 28th, 2019)**
- **2 GeV Protons Available**

**Data Extracted by PI Planning - June 2014**

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**IEEE/CSC SUPERCONDUCTIVITY NEWS FORUM (global edition) July 2014**

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**PREPARED BY P. ARNOLD & L. LABI**

**CHECKED BY J. WEISEND**

**APPROVED BY M. LINDROOBS**

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**High Level Schedule**

**ICEC 25 – J.G. Weisend II**
Summary

- Cryogenics will play a major role in ESS and affects the accelerator, target and instruments projects

- Work is well underway
  - A very skilled team has been assembled
  - Industry studies for the largest of the plants have been completed
  - Conceptual designs and technical specifications are complete or under preparation
  - Required buildings and utilities have been defined and are under detailed design
  - Sizable procurements will start in 2014 and 2015

- Significant Opportunities for IKC exist

- ESS has just received the green light to start construction